United States
Environmental Protection
Agency

EPA/600/R-00/052

June 2000

Research and Development

GREENHOUSE GASES FROM SMALL-SCALE COMBUSTION DEVICES IN DEVELOPING COUNTRIES: PHASE IIA

Household Stoves in India

Prepared for

Office of Air and Radiation

Prepared by

National Risk Management
Research Laboratory
Research Triangle Park, NC 27711

FOREWORD

The U. S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory is the Agency's center for investigation of technological and management approaches for reducing risks from threats to human health and the environment. The focus of the Laboratory's research program is on methods for the prevention and control of pollution to air, land, water, and subsurface resources, protection of water quality in public water systems; remediation of contaminated sites and-groundwater; and prevention and control of indoor air pollution. The goal of this research effort is to catalyze development and implementation of innovative, cost-effective environmental technologies; develop scientific and engineering information needed by EPA to support regulatory and policy decisions; and provide technical support and information transfer to ensure effective implementation of environmental regulations and strategies.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

E. Timothy Oppelt, Director
National Risk Management Research Laboratory

EPA REVIEW NOTICE

This report has been peer and administratively reviewed by the U.S. Environmental Protection Agency, and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

EPA/600/R-00/052
June 2000

GREENHOUSE GASES FROM SMALL-SCALE COMBUSTION DEVICES IN DEVELOPING COUNTRIES
Phase IIa

Household Stoves in India

by

Kirk R. Smith
Environment Program, East-West Center, Honolulu, HI 96848-1601 and
Environmental Health Sciences, University of California, Berkeley, CA
94720-7360

R. Uma, V.V.N. Kishore, K. Lata, V. Joshi
Tata Energy Research Institute, New Delhi 110003, India

Junfeng Zhang
Environment Program, East-West Center, Honolulu, HI 96848-1601 and
Environmental and Occupational Health Sciences Institute
Piscataway, NJ 08854

R.A. Rasmussen
Oregon Graduate Institute of Science and Technology
Beaverton, OR 97006

M.A.K. Khalil
Portland State University
Portland, OR 97207

EPA Cooperative Agreement CR820243-01
with the East-West Center, Honolulu, HI

EPA Project Officer: Susan A. Thorneloe
Atmospheric Protection Branch
Air Pollution Prevention and Control Division
Research Triangle Park, NC 27711

Prepared for:
U.S. Environmental Protection Agency
Office of Research and Development
Washington, DC 20460

FOREWORD

Early in the 1990s, a pilot study was conducted in Manila, Philippines, to measure the concentrations of a range of greenhouse gases from small-scale cookstoves burning biomass, charcoal, kerosene and liquefied petroleum gas (Smith *et al.*, 1992; 1993). Based on intriguing results, a more comprehensive study to characterize the emissions of non-CO_2 gases and other pollutants from cookstoves using different solid, liquid, and gaseous fuels was undertaken in China and India under a project organized by East-West Center (EWC) and funded by the US Environmental Protection Agency (USEPA). The study focuses on more than two dozen of the most common fuel/stove combinations in each nation. Since these countries contain more than half of all stoves in developing countries, the stoves in this study represent a large fraction of the combinations in use world-wide. In this report we describe the methodology and results of the study undertaken in India. The monitoring took place in a simulated kitchen built at the Gual Pahari Campus of the Tata Energy Research Institute (TERI), just outside New Delhi. Laboratory analyses took place at TERI and at the Oregon Graduate Institute of Science and Technology (OGIST).

ABSTRACT

This report presents a database containing a systematic set of measurements of the CO_2, CO, CH_4, TNMOC, N_2O, SO_2, NO_2, and TSP emissions from the most common combustion devices in the world, household stoves in developing countries. A number of different stoves using 8 biomass fuels, kerosene, LPG, and biogas were examined – a total of 28 fuel/stove combinations. Since fuel and stove parameters were monitored as well, the database also allows examination of the trade-off of emissions per unit fuel mass, fuel energy, and delivered energy as well as construction of complete carbon balances. Confirming the preliminary results in the Manila pilot study, the database shows that solid biomass fuels are typically burned with substantial production of PIC (products of incomplete combustion). In addition, as has often been shown in the past, biomass stoves usually have substantially lower thermal efficiencies than those using liquid and gaseous fuel. As a result, the emissions of CO_2 and PIC per unit delivered energy are considerably greater in the biomass stoves. In general, the ranking follows what has been called the "energy ladder" from lower to higher quality fuels, i.e., emissions decrease and efficiencies increase in the following order: dung-crop residues-wood-kerosene-gas. There are variations, however, depending on specific stove designs.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

GLOSSARY

Acacia	tree used as source of woodfuel in tests
BIS	Bureau of Indian Standards
COV	coefficient of variation = (standard deviation)/(mean)
EF_{bc}	emission factor per burn cycle experiment
EF_d	emission factor per MJ delivered to cooking pot (MJ_d)
EF_e	emission factor per unit net energy (MJ) of fuel
EF_m	emission factor per unit mass (kg) of fuel
Emission ratio	EF_{bc} molecular ratio of emitted specie (e.g., CO) to emitted CO_2
EPA	U.S. Environmental Protection Agency
ESI	Environmental Stove Index
Eucal	Eucalyptus, tree used as source of woodfuel in tests
EWC	East-West Center, Honolulu, HI
GHG	greenhouse gas (in this report: CO_2 CH_4, N_2O, CO, TNMOC)
Gross carbon balance	distribution of fuel carbon into gases, ash, char, and aerosol
GWC	global warming commitment = sum over i of GHG_i*GWP_i
GWP_I	global warming potentials in kg C as CO_2 per kg C in GHG (20-year time horizon) CO_2 = 1.0, by definition CO = 4.5 (IPCC, 1990) CH_4 = 22.6 (IPCC, 1995) TNMOC = 12 (IPCC, 1990) N_2O = 290 (IPCC, 1995), on a molar basis with CO_2 In the renewable case, 1.0 is subtracted from each (except N_2O) to account for the recycling of C as CO_2 in photosynthesis. Basic set - those with specified GWP in IPCC (1995) Full set - those with specified GWP in IPCC (1990, 1995)
Hara	traditional unvented mud stove for use with dung
HTE	heat transfer efficiency = η/NCE
imet	improved metal stove (unvented)
Instant emissions	from combustion of original fuel, with char left unburned
IPCC	Intergovernmental Panel on Climate Change
IREP	Integrated Rural Energy Planing Programme
ivc	improved vented ceramic stove
ivm	improved vented mud stove
Kero-pres	pumped kerosene stove (unvented)
Kero-wick	simple wick kerosene stove (unvented)
KVIC	Khadi and Village Industries Commission
LPG	liquefied petroleum gas contained in pressurized cylinders: butane and propane
MJ_d	megajoule delivered to the cooking pot
MNES	Ministry of Non-Conventional Energy Sources
NCAEC	National Council for Applied Economic Research

NCE	nominal combustion efficiency = fraction of airborne carbon emissions released as CO_2 = 1/(1+K) see **Eq. 2**
OGIST	Oregon Graduate Institute of Science and Technology, Beaverton
PIC	airborne products of incomplete combustion (CO, CH_4, TNMOC, TSP)
REDB	Rural Energy Database
ren	renewable, as in GWC (ren)
SRK	simulated rural kitchen
TERI	Tata Energy Research Institute, New Delhi
3-R	traditional 3-rock stove (unvented)
Tg	teragram = 10^{12} g = one million tons
tm	traditional mud stove (unvented)
TNMOC	total non-methane organic compounds (molecular weight taken as 18/carbon atom)
Tons	metric tons
TSP	Total Suspended Particulates
Ultimate emissions	instant emissions plus emissions from burning leftover char
η	overall energy efficiency of a stove (**Appendix D**)

ACKNOWLEDGEMENTS

We wish particularly to thank A.G. Rao and S. Mande of TERI for assistance with sampling and laboratory analysis as well as the staff members of the TERI Gual Pahari Campus workshop. In addition, we appreciate the advice and support of R.K. Pachauri, Director of TERI. At OGIST, we appreciate the help of D. Stearns, and at the University of California, David Pennise and Sharon Gorman.